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CHAPTER 4.11
FLAME-CUT PARTS

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THE PROCESSES

Oxygen (Flame) Cutting

This procedure is defined as a group of cutting processes through which the severing or removing of metals is effected by means of the chemical reaction of oxygen with the base metal at elevated temperatures. With oxygen cutting, a small area of the metal is preheated with oxygen and a fuel gas to the ignition temperature of the workpiece material. Then a stream of pure oxygen is directed onto the heated area. The oxygen rapidly oxidizes the workpiece material in a narrow section (the *kerf*) as the molten oxide and metal are removed by the kinetic energy of the oxygen stream. The thermal energy generated by the oxidation is a significant factor in the propagation of the process.

The process uses a torch with a tip whose functions are (1) to mix the fuel gas and the oxygen in the right proportion to produce the initial heating and continuous preheating and (2) to supply a uniformly concentrated stream of high-purity oxygen to the reaction zone for the purpose of oxidizing and removing the molten materials. The torch unit is then moved (manually or by machine) across the material to be cut at a controlled speed sufficient to produce a continuous cutting action. The fuel gases most commonly used for oxygen cutting are acetylene, natural gas, propane, and MAPP gas (a proprietary formulation).

The process is also known as *gas cutting* or *oxyfuel gas cutting.*

Cutting machines range from small, portable units that cut straight lines, bevels, and circles to large, 24-torch computer-controlled flame-cutting systems. Within this range are many small- to medium-sized general-purpose machines as well as machines designed for specific applications. Figure 4.11.1 shows a multiple-torch computer-controlled machine in operation.

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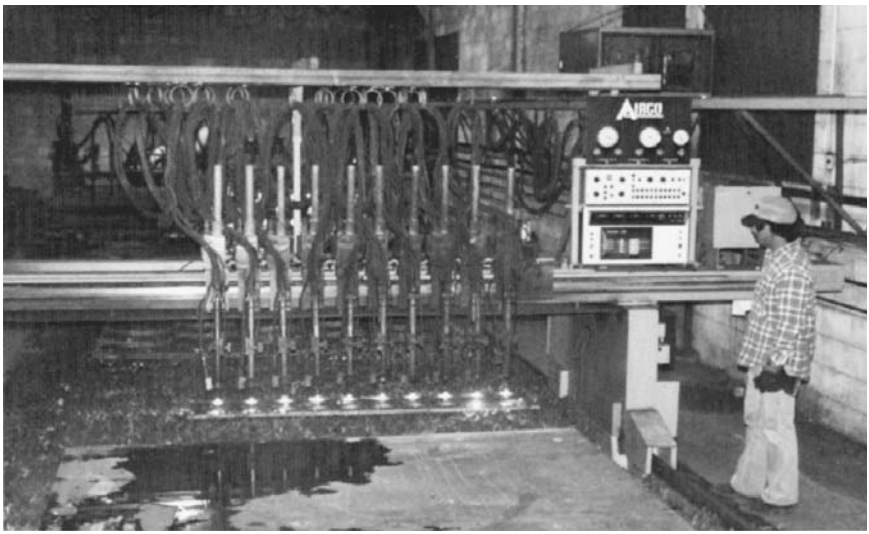

FIGURE 4.11.1 Multiple cutting with a numerically controlled flame-cutting machine. (*Courtesy Airco Welding Products Division, The BOC Group, Inc.*)

Plasma Cutting

Newer than oxygen cutting, plasma cutting is a metal-removal process that uses equipment similar to that used for the earlier process. Plasma is the state of matter produced when a gas is subjected to intense electrical and/or thermal forces that cause the molecules to be broken down to ions. When a high-voltage electric arc is used, the arc heats the gas until some of its atoms momentarily lose one or more electrons (this process is called *ionization*). As the ionized gas is expelled from the torch nozzle, the atoms regain their missing electrons and release energy previously absorbed by the ionization process. This recombination energy is added to the energy of the electric arc to produce an intensely hot flame. The plasma flame from the torch tip hits the workpiece in a thin, high-energy jet. Metal in the path of the plasma jet is melted or vaporized and washed through the kerf. A plasma-cutting machine can make fast, square, clean cuts in all types of electrically conductive materials. Its primary use is for nonferrous materials.

Guidance of the Torch

The key to successful application of the flame-cutting process is smooth, accurate guidance of the cutting tool, the torch-tip combination. This led to the introduction and widespread use of the cutting machine.

A *tracing template* is a full-size pattern used to guide the cutting of required shapes from metal plate. It can be compared to a tailor's pattern used to cut fabric. In electronic tracing, a line or edge template drawing provides a path for an electrooptical tracer to follow that, through a servo system, causes the machine to move the torches along a path of the same shape. The resulting cut part will be identical to the template

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if the effect of the diameter (kerf) of the cutting-oxygen stream is neglected. For this reason, *kerf compensation* is used to attain the correct dimension.

Computer and Numerical Control

Computer- and numerical-controlled flame cutters use neither template nor drawings but, instead, utilize perforated or magnetic tape, magnetic disks, or integrated memory circuits that carry, in digital form, the description of the part to be cut. The memory device also has "commands" relating to cutting speeds, burner ignition, register points, and other ancillary functions. The computer can develop an optional layout of cut parts on the plate stock to achieve maximum utilization of the material. Its display can prompt the operator to perform the correct sequence of steps in setting up and operating the flame cutter.

CNC units can store libraries of preprogrammed shapes that can be used to simplify the programming of new parts. Setup is greatly accelerated.

TYPICAL CHARACTERISTICS AND APPLICATIONS

Flame-cut parts are normally made from flat plate. Shapes that can be oxygen- or plasma-cut vary from simple rectangles and circles to complex curves and contours. Straight-line segments can be of any length. The machine components carrying the cutting torches ride on tracks, and track extensions can be added as necessary.

Contoured shapes may be simple arcs or circles or may employ compound, complex curves. Round and irregular-shaped holes are also feasible. Figure 4.11.2 illustrates typical examples of flame-cut shapes.

The flame-cut edge of a workpiece is normally perpendicular to the plate surface. It also may be beveled, with or without lands, or double-beveled (beveled top and bottom). Beveled edges are normally ready for welding immediately after flame cutting. Beveling with oxyfuel torches requires special steps, but beveling with plasma is routine; in fact, bevel cuts made with plasma are often superior to comparable perpendicular plasma cuts.

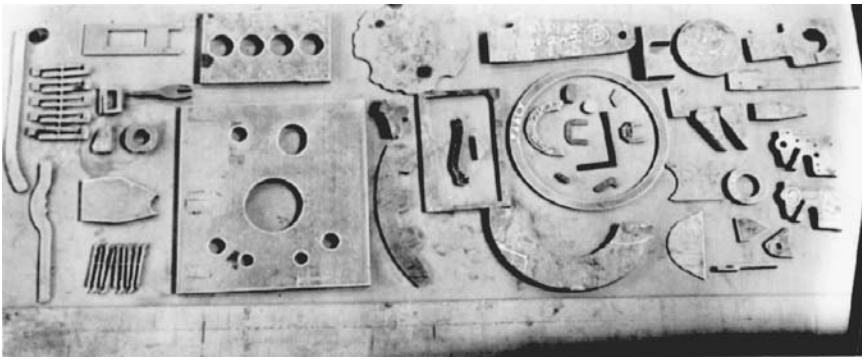

FIGURE 4.11.2 Typical flame-cut parts. (*Courtesy Airco Welding Products Division, The BOC Group, Inc.*)

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Plasma cutting of stainless steel gives favorable results in edge quality. The face of the cut is smooth and clean, the edges are sharp, and there is almost no slag. For carbon steel, however, the quality of the edge may not be as good with plasma as with oxyfuel gas.

Plate thicknesses of commercial significance are generally within the range of 3 to 300 mm ($\frac{1}{8}$ to 12 in), but cuts in stock as thick as 2.4 m (94 in) are possible. Sheets less than 3 mm ($\frac{1}{8}$ in) thick are usually flame-cut only in stacks.

Plates up to 4 m (12 ft) wide and of any practical length can be flame-cut with most equipment. In optical, tracer-controlled machines, maximum sizes usually range from 1.2 to 4 m (48 to 144 in). Machines of 18-m (60-ft) width capacity are also available and are guided by numerical control. The minimum size for flame-cut parts depends on practical and economic factors. Parts with a major dimension less than 25 or 50 mm (1 or 2 in) are usually more economically made by other methods.

Conventional oxygen cutting is limited to ferrous metals and titanium, while plasma cutting is applicable to any metallic material. Plasma-cut parts may not be as thick as parts cut with oxyfuel. The principal benefits of plasma cutting are realized on thicknesses of 32 mm ($1\frac{1}{4}$ in) or less. Plasma cutting of thicknesses over 64 mm ($2\frac{1}{2}$ in) entails a reduction in edge quality and an increased energy requirement that may offset the increased speed of the process. For thicknesses over 75 mm (3 in), plasma cutting is generally slower than oxyfuel cutting; the maximum thickness is 115 mm ($4\frac{1}{2}$ in).

With oxygen cutting, a large quantity of heat is liberated in the kerf. Much of this thermal energy is transferred to the area adjacent to the kerf at a temperature above the critical temperature of steel. Since the torch is constantly moving forward, the source of heat quickly moves on and the mass of cold metal near the kerf acts as a quenching medium, rapidly cooling the heated metal. The steel hardens to a degree that depends on the amount of carbon and alloying elements present as well as on the thickness of the material being cut. With the more conductive alloy steels, quench cracks may appear at the surface.

The depth of the heat-affected zone ranges from 0.8 to 6 mm ($\frac{1}{32}$ to $\frac{1}{4}$ in). There is also a shallower zone of measurably increased hardness. From 0.4 to 1.5 mm ($\frac{1}{64}$ to $\frac{1}{16}$ in) deep, it exhibits an increased hardness of 30 to 50 points on the Rockwell C scale. This hardness can be removed by annealing but not by stress relieving. With plasma cutting these heat-affected zones are narrower.

Typical applications of flame-cut parts include shipbuilding, building construction and equipment components, pressure and storage vessel parts, blanks for gears, sprockets, handwheels, and clevises. The most common applications probably are heavy-walled parts to be welded as part of some frame or structure.

Specialized flame-cutting machines are used in the steel industry to sever billets, blooms, slabs, or rounds (with either hot or cold cutting). As in beveling, both plasma and oxyfuel gas also can be used for gouging and grooving, but plasma is simpler. Gouging is used extensively to remove deep defects in steel revealed by scarfing or by radiographic, magnetic, ultrasonic, and other inspection methods. Among other gouging applications are removing tack welds, defective welds, blowholes, or sand inclusions in castings, welds in temporary brackets or supports, flanges from piping and heads, and old tubes from boilers. Gouging also is used in demolition work and in the preparation of plate edges for welding.

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ECONOMIC PRODUCTION QUANTITIES

Flame cutting is generally more economical per inch of cut than other machine operations used to generate comparable shapes in steel plates. It is most advantageous for lower-quantity production. A run long enough to justify a substantial tooling investment would give casting, forging, or stamping a competitive advantage in many cases. The prime advantages of flame cutting are greatly reduced cost of tooling, minimum setup time, flexibility and simplicity of operation, and short lead time.

A not uncommon application of flame cutting is in maintenance work or one-of-a-kind production, in which the operator lays out the part outlines on the plate to be cut and then operates the cutting torch freehand or perhaps with the aid of a straightedge or compass.

Even in repetitive production, the special tooling is quite simple and inexpensive. It consists of a drawing (optical tracing), a template, or, with a computer-controlled machine, a stored program. The cost of these items is negligible compared with blanking or forging dies and is even far below that of a simple pattern for sand casting.

This low cost of tooling and the fast cutting action of the flame or plasma method ensure its economic advantage for low-quantity production. With multiple-torch machines (up to 16 torches) and stack cutting, the advantage extends to medium and, in some cases, to high levels of production.

Typical cutting rates are 20 to 30 in/min and range up to 120 in/min for oxyfuel cutting. For plasma cutting, rates are typically 50 to 125 in/min but can be as high as 300 in/min. Rates vary inversely with stock thickness. Use of multiple cutting torches effectively multiplies these rates when a series of parts is to be cut.

MATERIALS SUITABLE FOR FLAME CUTTING

Low-carbon steel and wrought iron are the best materials for flame cutting. Medium-carbon and low-alloy, low-carbon steels also are usually satisfactory. Processibility decreases as the carbon and alloy content increases. Nonferrous metals are normally not suitable for flame (oxygen) cutting because they do not oxidize readily. Galvanized steel, especially in thin gauges, also is not well adapted to flame cutting.

Conventional flame cutting is largely an oxidation process. As the amount and number of alloying materials increase, the oxidation rate decreases from that of pure iron. For ferrous metals with a high alloy content, such as cast iron and stainless steel, variations in normal oxygen-cutting methods must be used. These include preheating, torch oscillation, flux addition, and iron-powder addition to the flame.

Plasma cutting can be used on almost any metal, including metals difficult to flame-cut. Stainless steel and aluminum are the materials most frequently cut by the plasma process. Plasma cutting also makes fast, clean cuts in the following electrically conductive materials: brass, bronze, nickel, tungsten, mild steel, alloy steel, tool steel, Hastelloy, copper, cast iron, molybdenum, Monel, and Inconel.

Table 4.11.1 summarizes applicable cutting methods for the most commonly processed materials.

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TABLE 4.11.1 Applicable Cutting Methods for Commonly Flame-Cut Materials

Material	Method
Mild steel	Oxyfuel or plasma
Low-alloy steel	Oxyfuel or plasma
Titanium	Oxyfuel or plasma
High-alloy steel	Plasma
Stainless steel	Plasma
Copper	Plasma
Aluminum	Plasma

DESIGN RECOMMENDATIONS

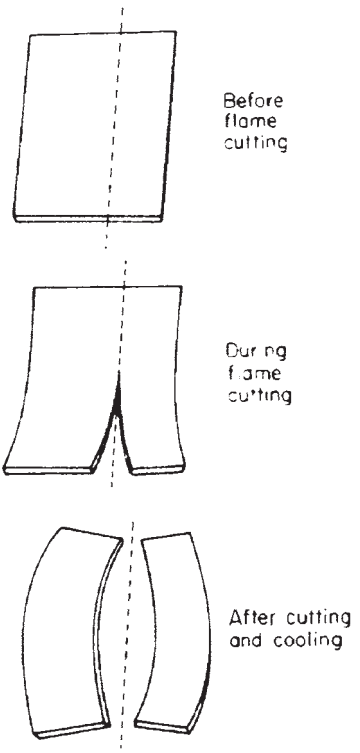

FIGURE 4.11.3 Deformation that occurs in flame cutting shown greatly exaggerated. Wide pieces (such as the left-hand piece) deform less than narrow pieces (such as the right-hand piece) because the larger unheated area resists deformation.

Heat Effects

It must be recognized that the flame-cutting process involves a chemical reaction between iron and oxygen with a resulting heat effect. With this condition existing, narrow sections may pick up extra heat and not be capable of resisting warpage; thin plates may buckle, or inadequate stock may not provide sufficient material for the reaction (see Fig. 4.11.3). However, water spray at the cut can eliminate some distortion problems on thin plate.

Usually distortion is severe enough to cause problems only in plate thinner than 8 mm ($\frac{5}{16}$ in). It is also more severe when long, narrow sections are cut. Therefore, it is advisable to design narrow sections to be as short as possible. (See Fig. 4.11.4.) Parts designed for balanced cutting heat by cutting on both sides will also have less distortion.

Kerf

It is important to allow for kerf when designing parts for flame cutting. Kerf widths range from approximately 1.3 mm (0.050 in) for 19-mm- ($\frac{3}{4}$-in-) thick material to 4 mm (0.150 in) for 200-mm- (8-in-) thick material. When templates are used, the size must be adjusted to allow for the kerf width.

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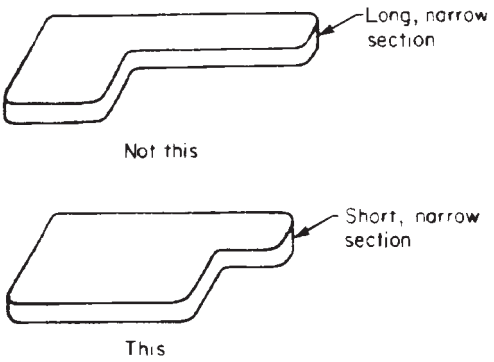

FIGURE 4.11.4 Design narrow sections to be as short as possible to avoid distortion.

Minimum Radii

Small radii, especially internal radii, are difficult to flame-cut. External corners can be sharp if the cutting torch moves past the corner, but this may reduce the usability of the plate material from which the workpiece is cut. Generous internal and external radii should be allowed whenever possible. Figure 4.11.5 illustrates normal minimum allowable radius dimensions for various plate thicknesses.

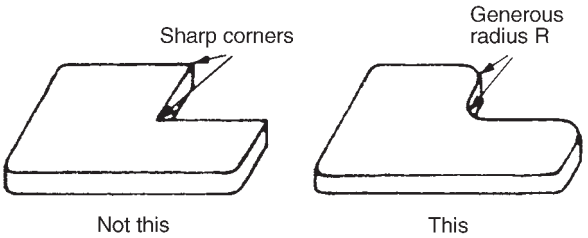

FIGURE 4.11.5 Minimum radius dimensions for various plate thicknesses.

Minimum Values of *R* (Internal Corners)

Plate thickness, mm (in)	*R* (minimum), mm (in)
6–75 (¼–3)	4 (5/32)
Over 75–150 (3–6)	5 (3/16)
Over 150–200 (6–8)	6 (¼)

Sweeping Curves

Generous fillets and sweeping curves produce a pleasing design effect, but if they are not required for structural strength, their omission may result in considerable cost sav-

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ings. A curved edge entails a large scrap loss and extensive cutting from even the most ideally sized rectangular plate. Rectangular shapes normally will result in a lower overall cost.

Machining Allowance

When flame-cutting tolerances do not meet the requirements of the finished part, flame cutting can be used to remove the major portion of the material, leaving enough stock for milling, drilling, boring, grinding, or other machining operations. When using flame cutting for rough stock removal and machining for finishing to final tolerances, allow at least 1.5 mm ($^{1}/_{16}$ in) of stock for finishing to minimize cutter damage due to the hardened material at the flame-cut edge.

Nested Parts

Designing parts so that they can be nested on the plate and employ common edges will make one cut do the work of two. It also will improve utilization of the plate material. This principle is the same as that which applies to metal stampings and is illustrated in Fig. 3.2.13.

Minimum Holes Size and Slot Widths

Holes and slots can be produced by flame cutting, but because of the kerf, there is a minimum size for such openings. This size varies with the plate thickness and is summarized in Table 4.11.2.

Specifying Quality of Cut

Not all flame cutting must be of the same quality. For workpieces for which either dimensional accuracy or appearance can be sacrificed, higher speeds and longer drags can be used. A shop can set up two or even three standards for quality, and designers can specify the quality required for each cut. The highest-quality level could specify

TABLE 4.11.2 Minimum Slot and Hole Sizes for Flame-Cut Parts

Plate thickness	Minimum slot size, width × length	Minimum hole diameter
6–35 mm (¼–1⅜ in)	8 × 19 mm (5/16 × ¾ in)	16 mm (⅝ in)
Over 35–75 mm (1⅜–3 in)	9.5 × 22 mm (⅜ × ⅞ in)	22 mm (⅞ in)
Over 75–100 mm (3–4 in)	13 × 25 mm (½ × 1 in)	32 mm (1¼ in)
Over 100–127 mm (4–5 in)	19 × 32 mm (¾ × 1¼ in)	41 mm (1⅝ in)
Over 127–165 mm (5–6½ in)	25 × 44 mm (1 × 1¾ in)	54 mm (2⅛ in)
Over 165–200 mm (6½–8 in)	38 × 64 mm (1½ × 2½ in)	64 mm (2½ in)

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flame-cut parts with square, smooth edges cut to close limits. This grade would apply to parts to be mated without further machine work or to parts to be joined by automatic welding. The second grade could call for good appearance but with lower standards of dimensional accuracy. A proper use for this grade of cut quality would be for lightening holes, the external edges of the equipment, or edges on which manual welding is to be performed. When further machine work is to be done on the cut surfaces, a third-grade cut might be used. In such cases, a mere severance cut might be sufficient.

When more detailed means of specifying cut quality are required, the American Welding Society (P.O. Box 351040, Miami, Fla. 33135) has a series of specifications that cover flatness, angularity, roughness, top-edge rounding, and notches. In any case, it is advisable that the design of the part to be flame-cut indicate the quality level required. Only the quality level needed for the function of the part should be specified. Specifying overly high quality levels unnecessarily increases product cost.

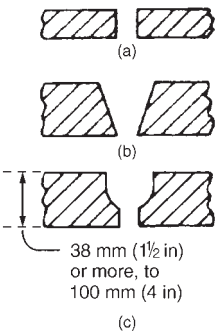

FIGURE 4.11.6 Edge configurations. The square or perpendicular edge of (*a*) is more economical. The V groove of (*b*) is relatively inexpensive to cut. The U groove of (*c*) is more expensive to cut but saves weld filler material and

Edge Design

Square edges as shown in Fig. 4.11.6*a* are most economical, but some rather complex edge designs can be produced in one or two passes by using multiple torches. Edge design for plate to be welded depends on the thickness of the weld, the required access for the welding gun to get root penetration, and the welding process to be used. Proper edge design reduces both filler-metal usage and welding labor.

Heavy plates over 38 mm ($1\frac{1}{2}$ in) thick are usually prepared for welding with chamfered or grooved edges. V grooves as shown in Fig. 4.11.6*b* are easy and inexpensive to cut but require more filler metal. J grooves prepared on each plate produce U grooves (Fig. 4.11.6*c*) when the edges are butted together. These contoured grooves are more costly to flame-cut but use less filler metal and are less expensive to weld.

Curved edges with bevels or grooves require special equipment or additional operator skill levels. They are therefore more expensive than perpendicular cuts and should be avoided if they are not necessary.

TOLERANCE RECOMMENDATIONS

Table 4.11.3 presents recommended dimensional tolerances for normal production conditions for various plate thicknesses. Closer tolerances can be obtained if conditions are optimal and extra care and time can be taken. However, the values shown should be used for most applications.

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TABLE 4.11.3 Recommended Dimensional Tolerances for Flame-Cut Parts

Plate thickness	Length, width, or hole or slot location	Hole or slot dimension
6–35 mm (¼–1⅜ in)	±1.5 mm (±0.060 in)	±0.8 mm (±0.030 in)
Over 35–75 mm (1⅜–3 in)	±1.5 mm (±0.060 in)	±1.2 mm (±0.045 in)
Over 75–100 mm (3–4 in)	±2.4 mm (±0.090 in)	±1.5 mm (±0.060 in)
Over 100–127 mm (4–5 in)	±2.4 mm (±0.090 in)	±2.4 mm (±0.090 in)
Over 127–165 mm (5–6½ in)	±2.4 mm (±0.090 in)	±3.0 mm (±0.125 in)
Over 165–200 mm (6½–8 in)	±3.0 mm (±0.125 in)	±3.0 mm (±0.125 in)

Note: Under the most precise conditions of template or computer-controlled cutting with a highly accurate template and no significant heat distortion, dimensions of ±0.6 mm ±0.024 in) can be held on plate 75 mm (3.0 in) thick or less.

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